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# Study of recent seismicity in the area of Southern Apennines.

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## Introduction

The Southern Apennines belong to the complex geodynamic setting characterizing the Central Mediterranean region, which is dominated by the NNW-SSE convergence between the European and African plates. The tectonics of this area is accommodated by the collision between the Adriatic microplate and the Apenninic belt. The eastward migration of the extension-compression system derived by the subduction process of the Adriatic microplate is related to the opening of the Tyrrhenian Sea. Seismological data and recent geodetic studies reveal that the Apennines are undergoing a NE-trending extension, with seismic deformation rates higher in the southern portion. Highly energetic events in the last four centuries are historically well documented. From the instrumental seismic catalogue 1981-2002 (Castello et al., 2005) we observe that most of the background seismicity is concentrated along the Apenninic chain (Fig. 1). In this work, we have analyzed the seismicity of the last 6 years (2001-2006) recorded by the Italian National Seismic Network (RSNC) and by the temporary seismic array of the SAPTEX experiment (2001-2004) (Cimini et al., 2006). The denser station coverage, with respect to that available in the past years, yields a significant improvement in the hypocentral locations. We used standard seismological methods to compute Vp/Vs ratio, one-dimensional velocity model, and station corrections for earthquake relocations. Focal mechanisms were computed using first motion polarities. We apply Gephart (1990) procedure to our fault-plane solution data set for investigating the stress field in the region.

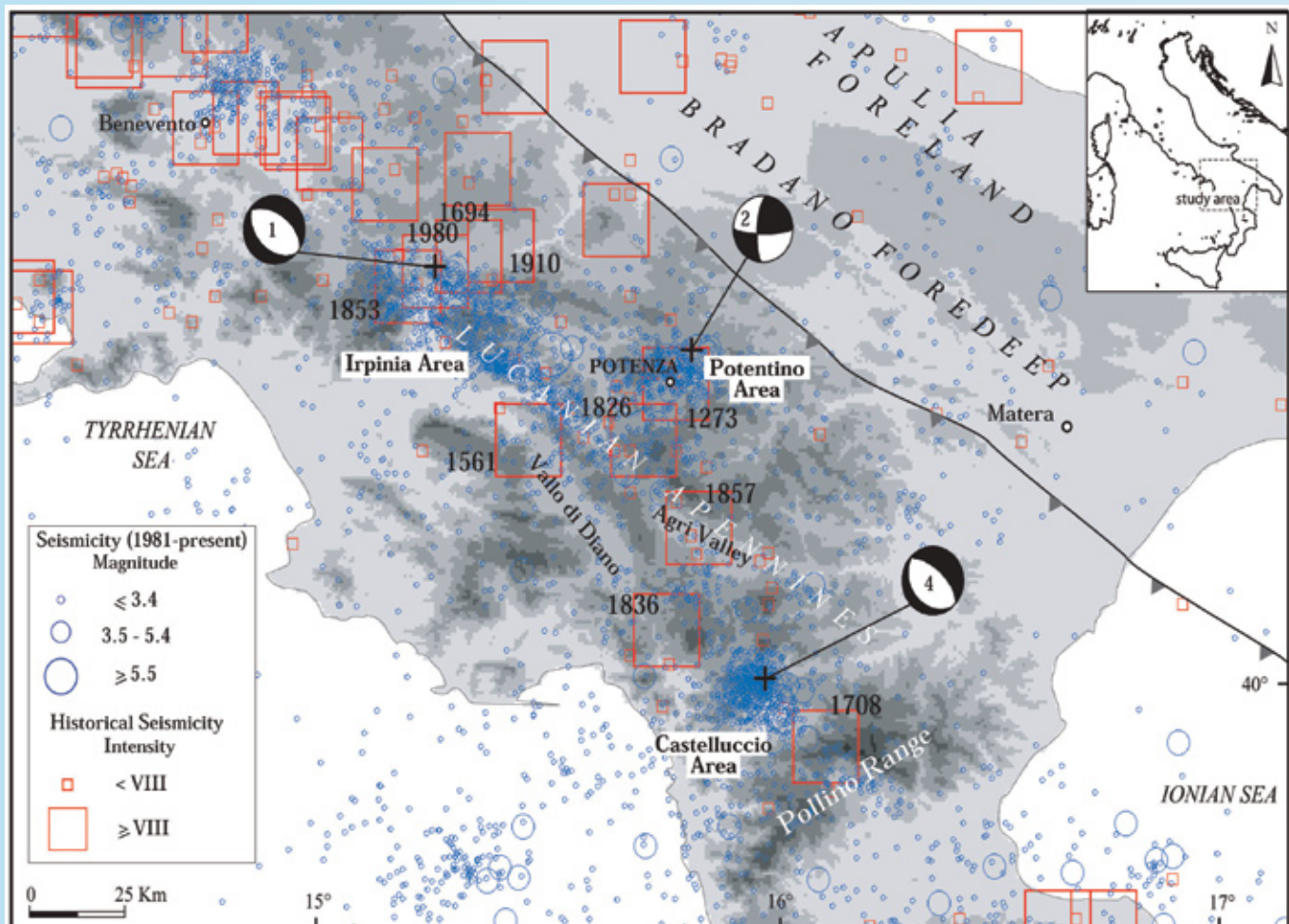


Fig.1. Seismicity of Southern Italy from 1981 to 2005 (CPTI Working Group, 1999; Castello et al., 2005). Historical earthquakes are shown with the year of occurrence close to unfilled red squares with size proportional to the estimated magnitude. Focal mechanisms of the largest events in the Southern Apennines in the last 27 years are also shown (Irpinia 1980, Potentino area 1990 and 1991, Castelluccio area 1998).

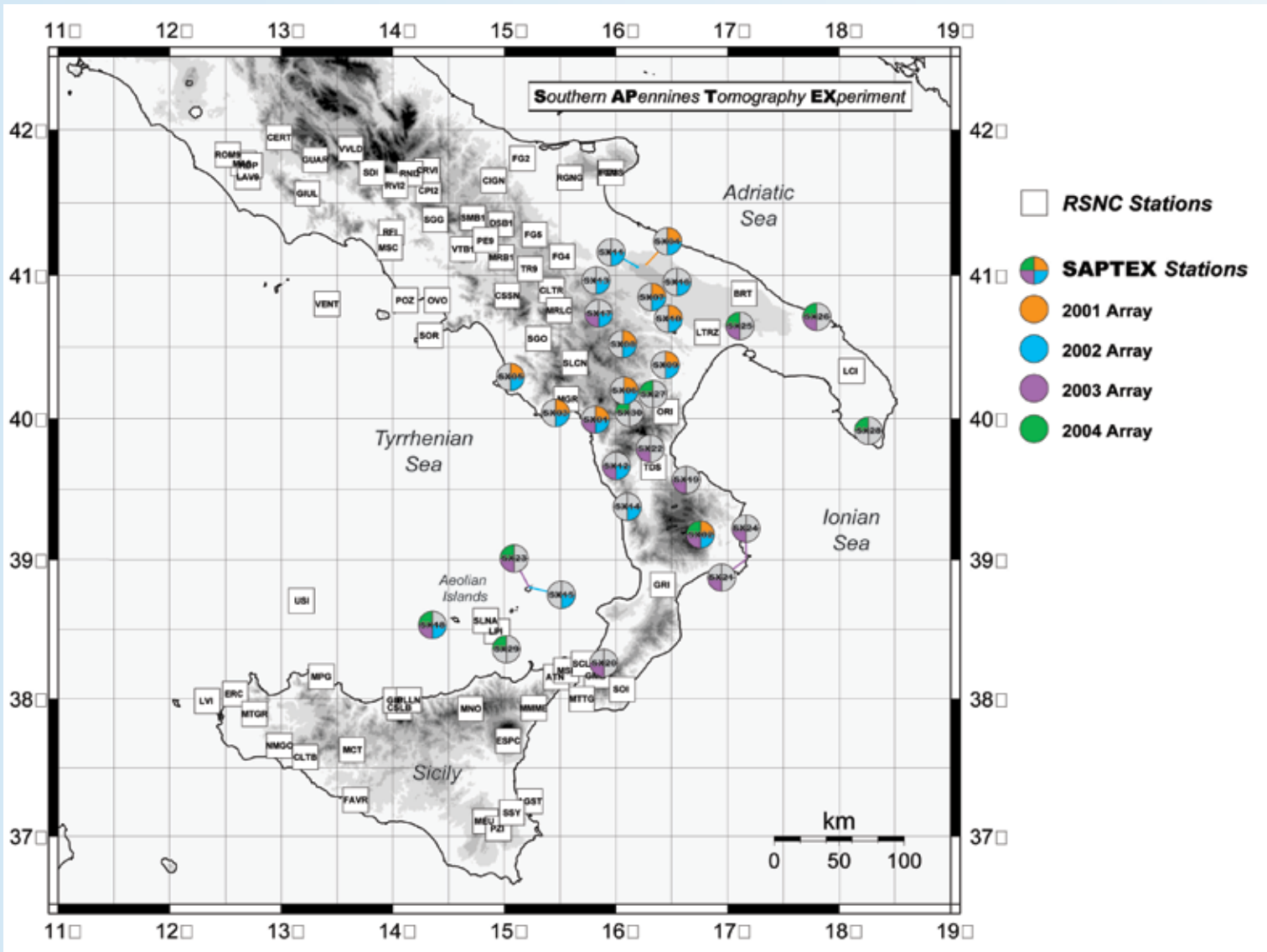


Fig.2. Italian National Seismic Network (RSNC) and SAPTEX temporary seismic stations. With white squares are shown the permanent stations of the RSNC and with circles are shown the temporary stations deployed for the SAPTEX tomographic experiment during 2001 (orange), 2002 (blue), 2003 (magenta), and 2004 (green) (Cimini et al., 2006).

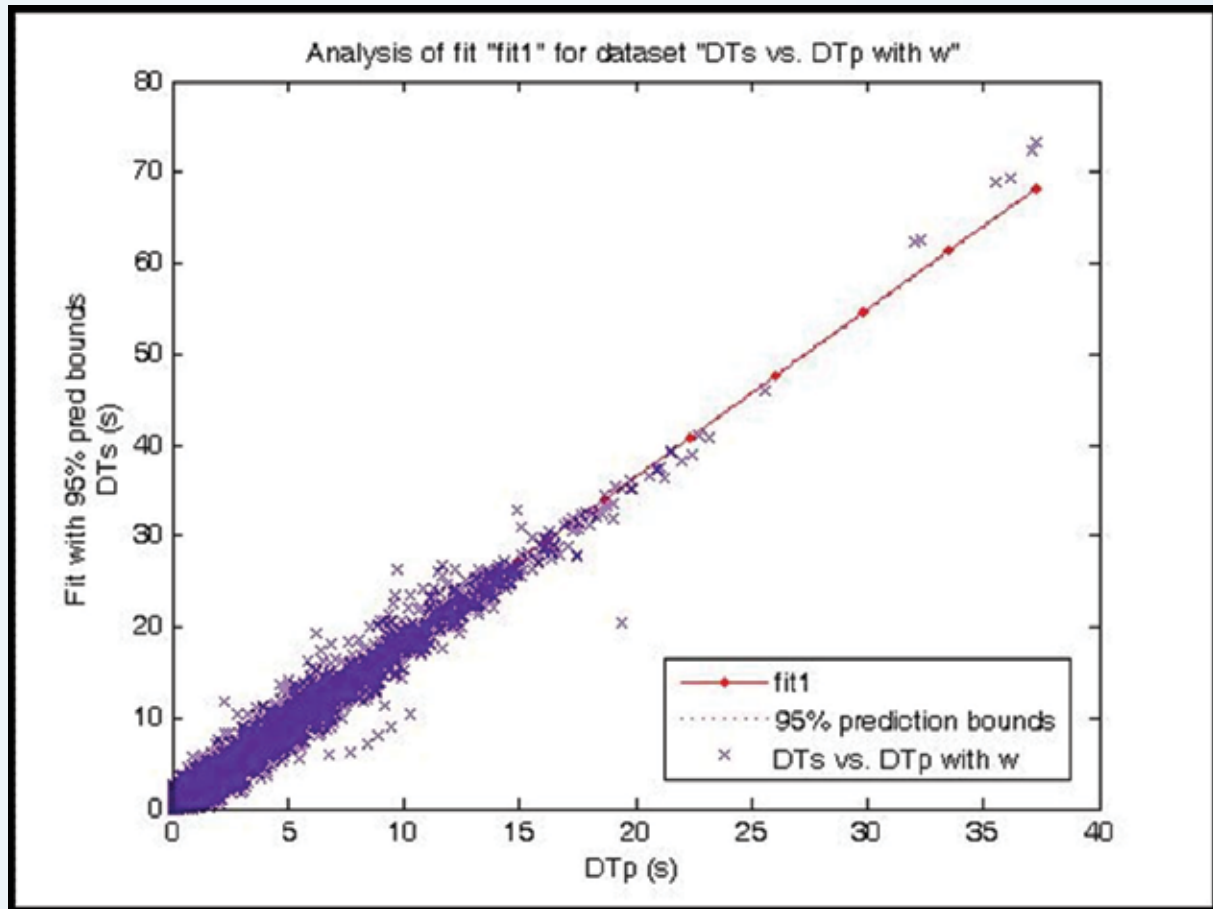


Fig.3. Linear fit of DTs versus DTP with 95% prediction bounds. The root mean squared error (RMSE) is 0.40, and the linear correlation coefficient (R) is 0.87. We plotted values with weights of 0, 1 or 2, considering the highest one among the four P and S weights (Pointoise and Monfret, 2004).

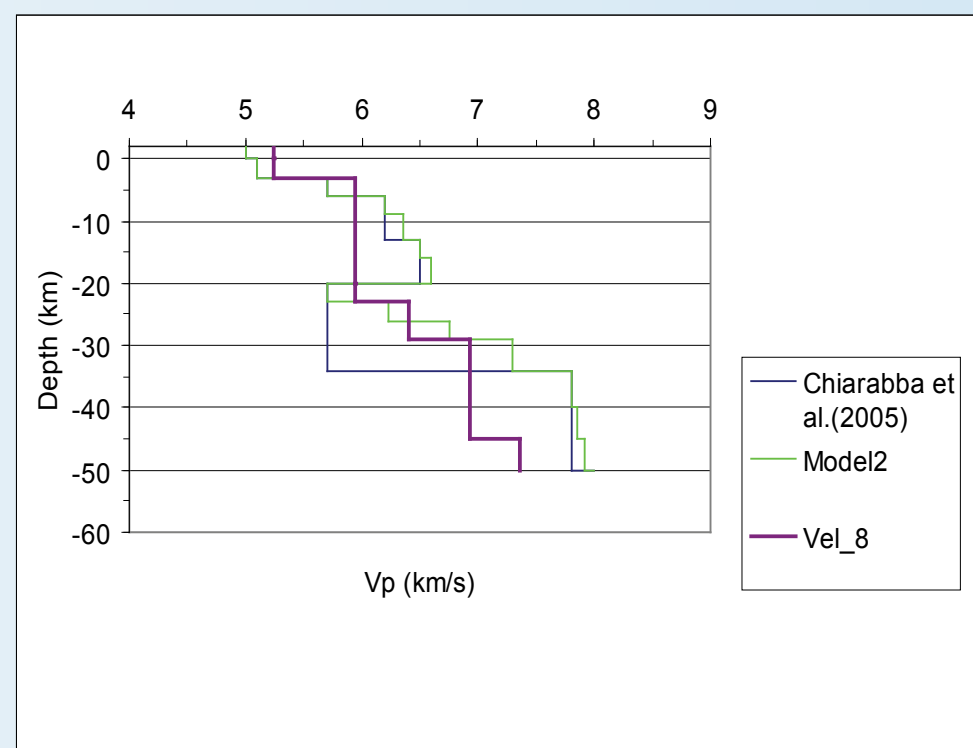


Fig.4. Starting P-wave velocity model for the Italian region computed by Chiarabba et al. (2005). We restratified this initial model introducing some layers with thickness of 3 or 4 km, up to 30 km depth, and of 5 km for greater depths. We named this model *Model2*. *Vel\_8* is the final velocity model obtained with VELEST.

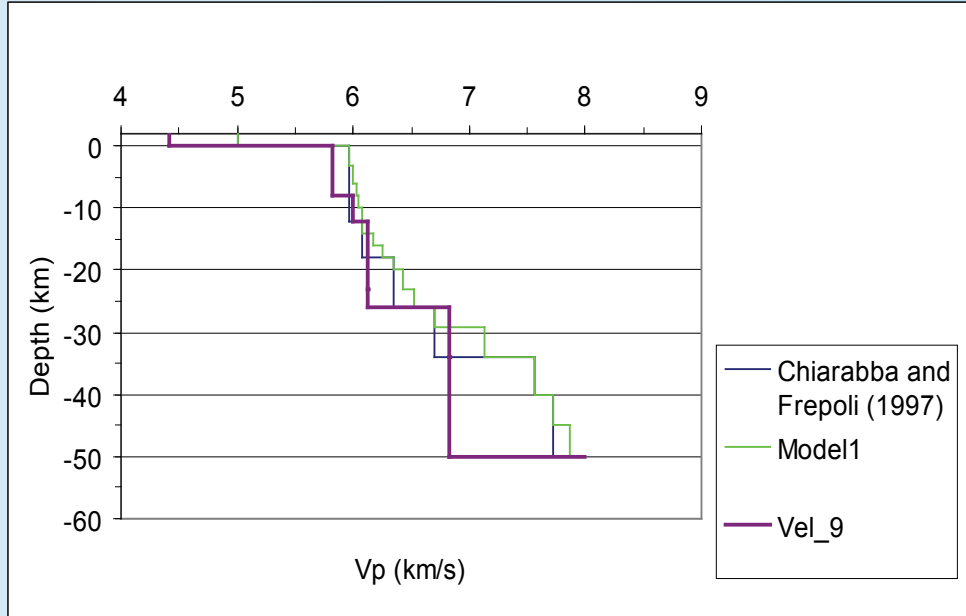


Fig.5. Starting P-wave velocity model for the Southern Italy by Chiarabba and Frepoli (1997). We restratified this starting model introducing some layers with thickness of 3 or 4 km, up to 30 km depth, and of 5 km for greater depth. We named this model *Model1*. *Vel\_9* is the final velocity model obtained with VELEST.

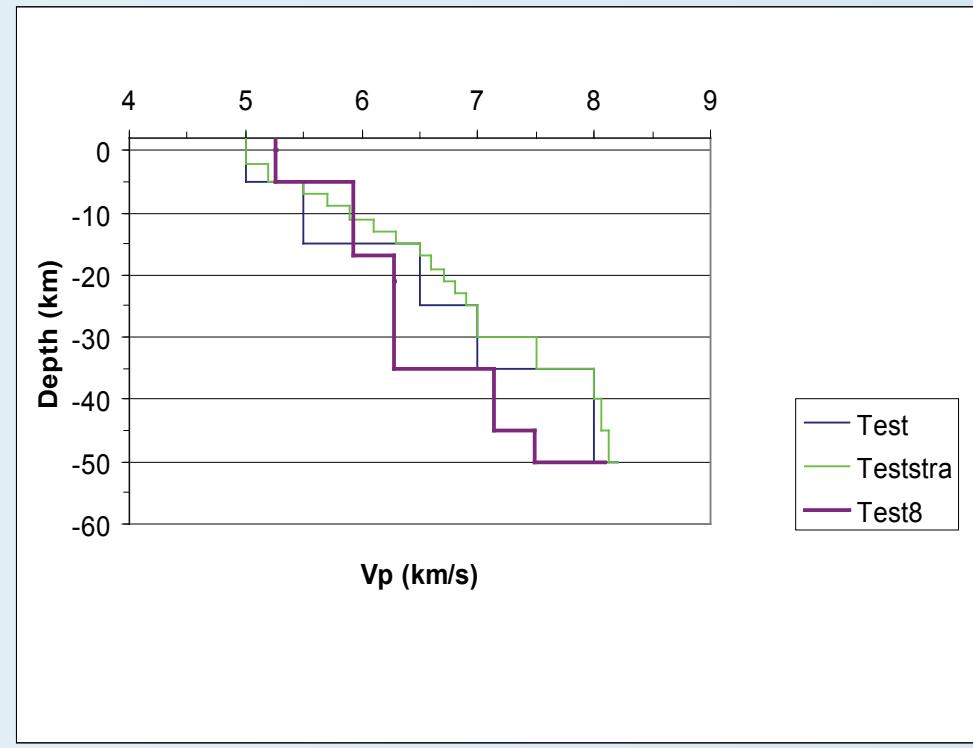


Fig.6. Starting P-wave velocity model Test for the Lucanian Apennines. We restratified this model introducing some layers with thickness of 3 or 4 km, up to 30 km depth, and of 5 km for greater depths. We named this model *Teststra*. *Test8* is the final velocity model obtained with VELEST.

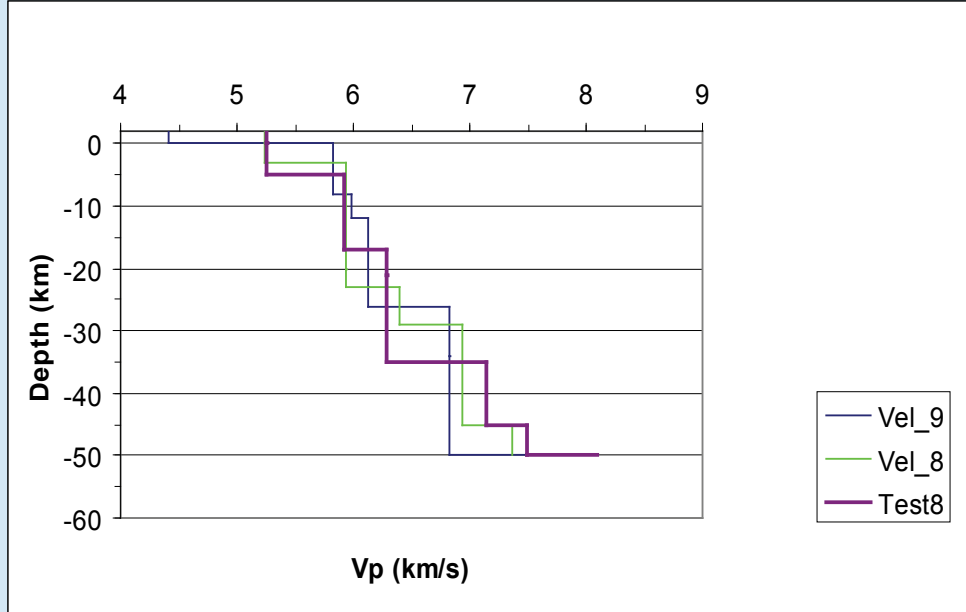


Fig.7. P-wave velocity final models obtained with VELEST. *Vel\_8* is the model derived from *Model2*, *Vel\_9* from *Model1* and *Test8* from *Teststra*.

## Data and 1D velocity model

We analyzed the seismicity of the Lucanian Apennines and Bradano foredeep in Southern Italy that occurred in the period June 2001 - December 2006. We re-picked P- and S-wave arrival times, for a total of 7570 P- and 4956 S-phases of 514 earthquakes with local magnitude (MI) larger than 2.0. We computed an average Vp/Vs ratio using a modified Wadati method (Chatelain, 1978) obtaining a value of 1.83 (Fig.3). To better constrain the hypocentral depths we performed an analysis to find the best P-wave one-dimensional (1D) velocity model for the crustal seismic structure of the study area, using the VELEST algorithm (Kissling et al., 1995). We considered three starting models: 1) model obtained by Chiarabba et al. (2005) for the Italian region (Fig.4); 2) model by Chiarabba and Frepoli (1997) computed for the seismic structure of Southern Italy (Fig.5); 3) a P-wave velocity model named *Test* that we obtained from other Lucanian Apennines seismic studies (Frepoli et al., 2005, Cassinis et al., 2003) (Fig.6). As VELEST program doesn't invert for changes in layer thicknesses, we restratified the initial models (stratified models: *Model2*, *Model1* and *Teststra*) finding a more appropriate model layering. After some tests, we derived the models in Fig.7 (*Vel\_8*, *Vel\_9* and *Test8*). Since the models *Vel\_8* with root mean square RMS=0.33, and *Test8*, with RMS=0.32, converged we used both to relocate our dataset using the HYPOELLIPSE code (Lahr, 1989).

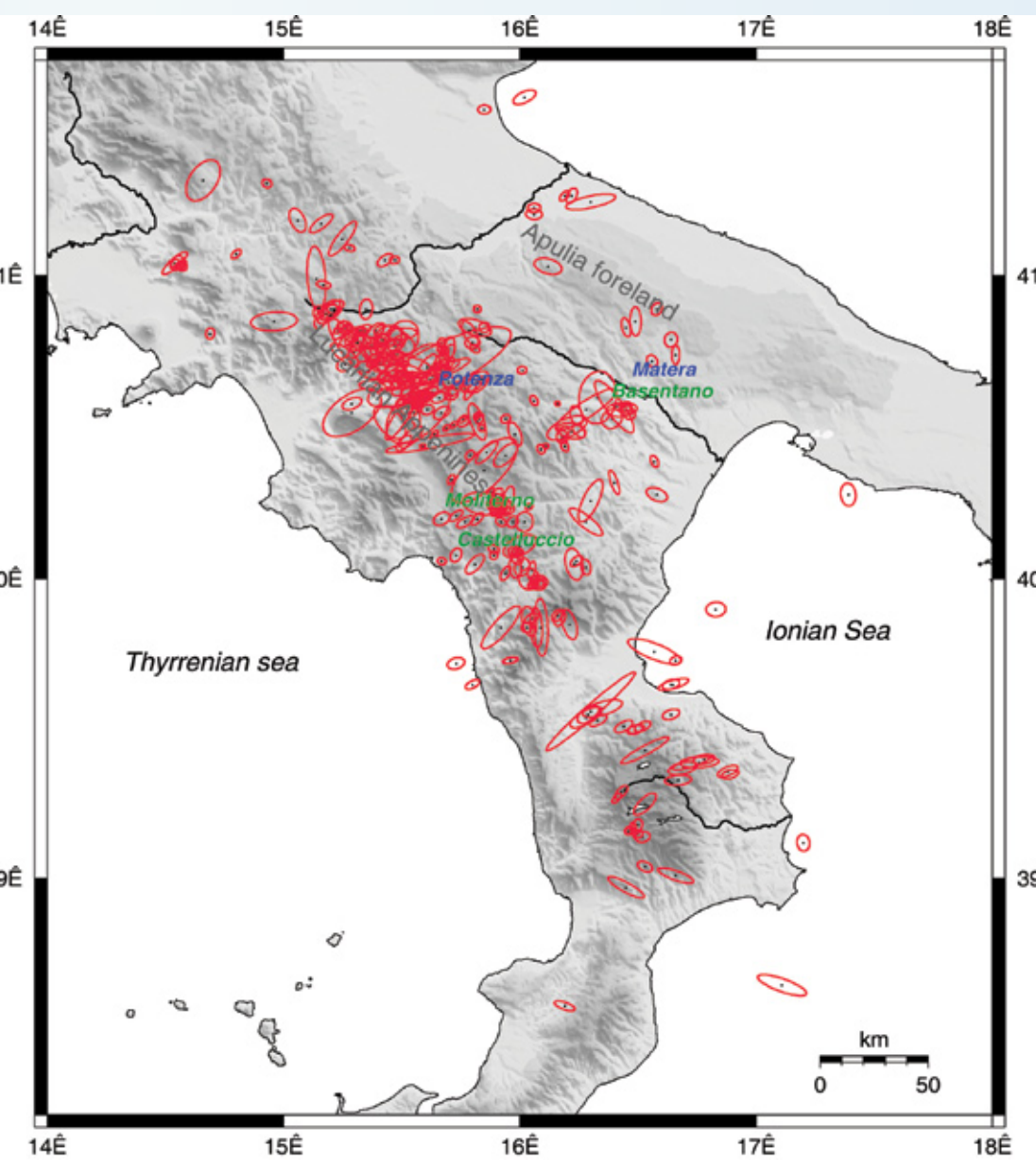


Fig.10. Location hypocenters and error ellipse (multiplied for three) of events with quality A, B and C. This figure highlight results goodness.

Qualità	Larger of SEH and SEZ	Number of events of the model Test8	% number of events of the model Test8	Number of events of the model Vel_8	% number of events of the model Vel_8
A	≤ 1.34	243	67.7%	173	56.90%
B	≤ 2.67	59	16.40%	70	23.10%
C	≤ 5.35	25	7.00%	36	11.80%
D	> 5.35	32	8.90%	25	8.20%

Table I. Hypocentral quality based on the value of the horizontal SEH (68% confidence limit), and vertical SEZ (68% confidence limit) errors.

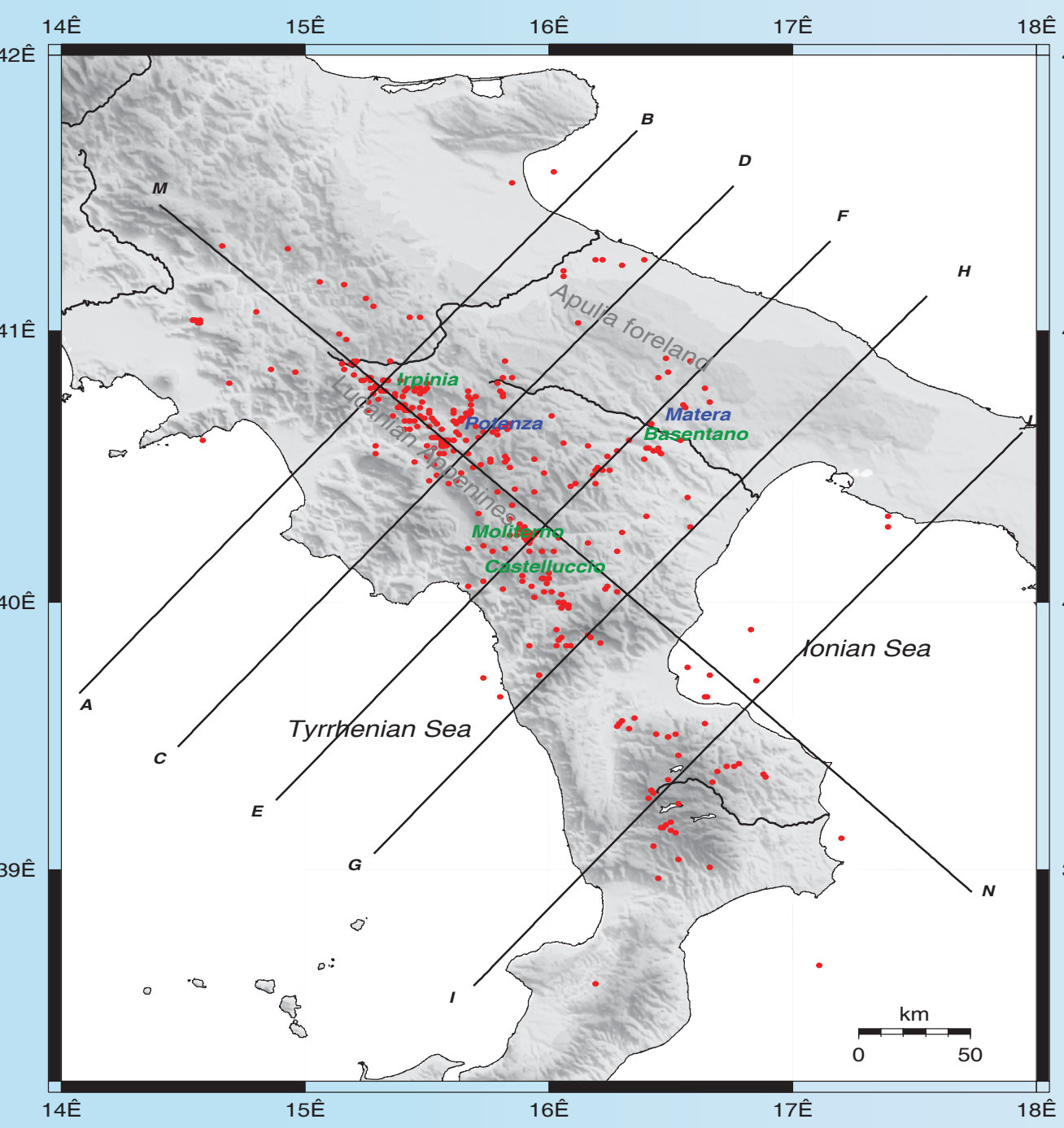


Fig.8. Horizontal distribution of 359 earthquakes located using the model *Test8*. The width of cross-sections AB, CD, EF, GH, IL is 25 km and of MN 200 km, respectively.

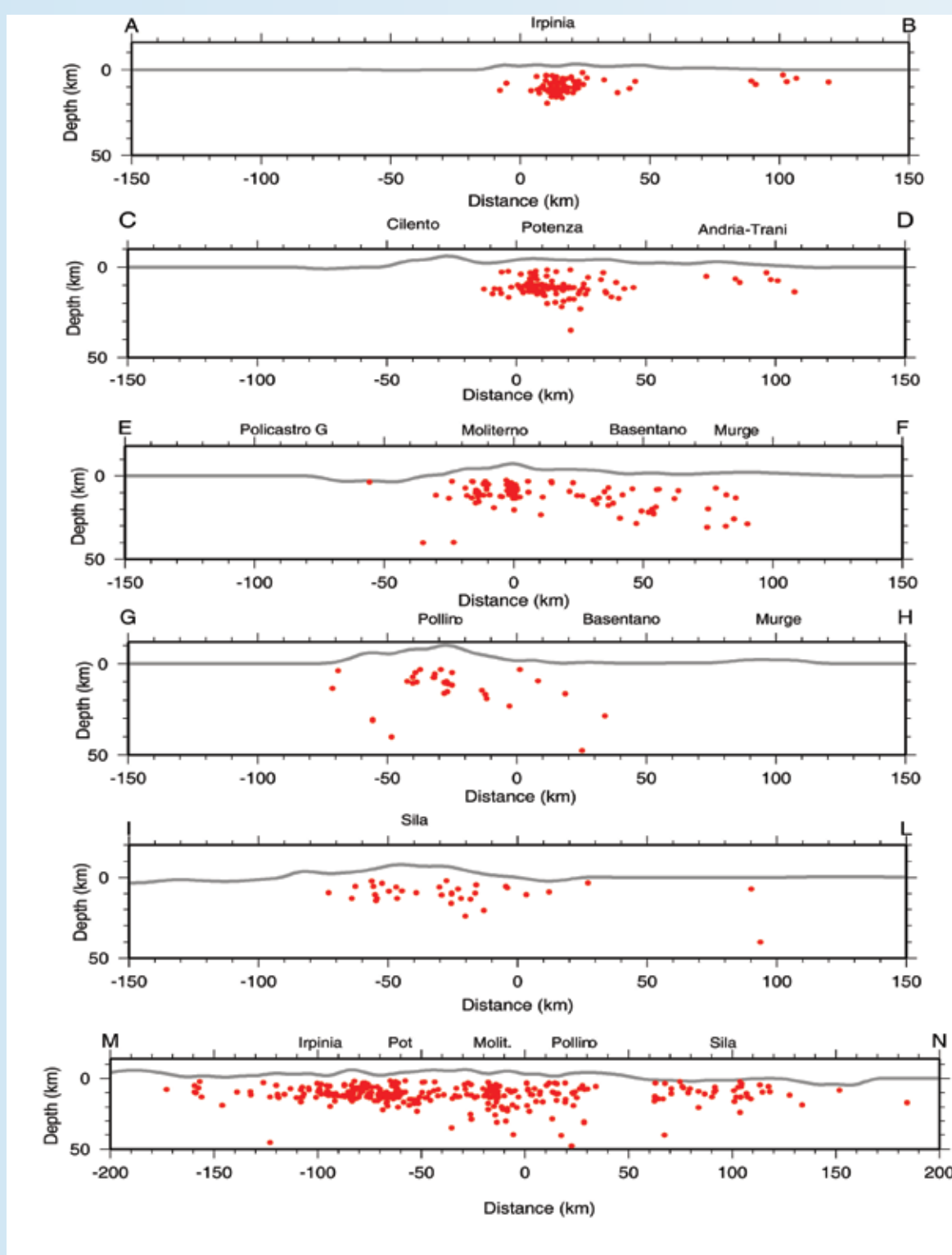


Fig.9. Depth distribution of 359 events located with HYPOELLIPSE using the model *Test8*.

## Relocation

We rejected the earthquakes with azimuthal gaps larger than 180° and root mean square larger than 1 s. Using these criteria, we relocated 304 events (56.9% with quality A and 23.1% B) for the model *Vel\_8*, and 359 (67.7% with quality A and 16.4% B) for *Test8*, respectively (Table I). The results indicate that the model *Test8* is more appropriate than model *Vel\_8*. The epicentral distribution of the local earthquakes relocated using the model *Test8* with HYPOELLIPSE is shown in Fig.8 and Fig.9. Fig.10 shows the ellipses error multiplied for three, to estimate goodness of hypocenter locations. The results of relocation were characterized by majority of events with: RMS of 0.2-0.3 s, maximum horizontal error (Max\_Err\_H) 0.12-1.2 km and vertical error (Err\_Z) 0-1 km (Fig.11).

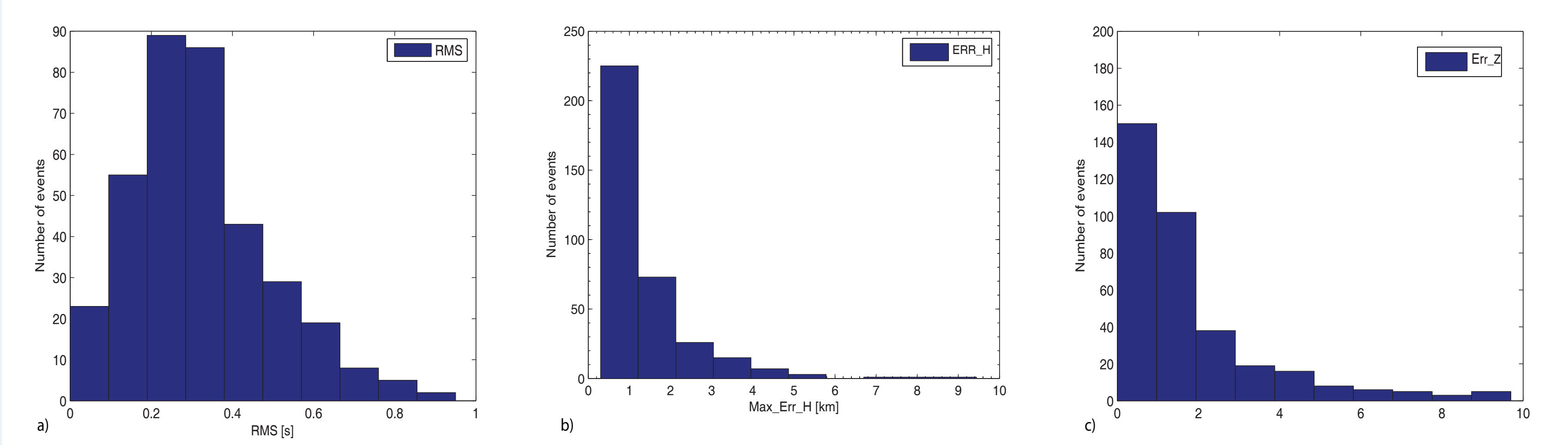


Fig.11. Distribution of: RMS values a); maximum horizontal error (Err\_H) b); distribution of vertical error (Err\_Z) c) for the events location. In b) and c) we considered only events with horizontal and vertical errors less than 10 km.

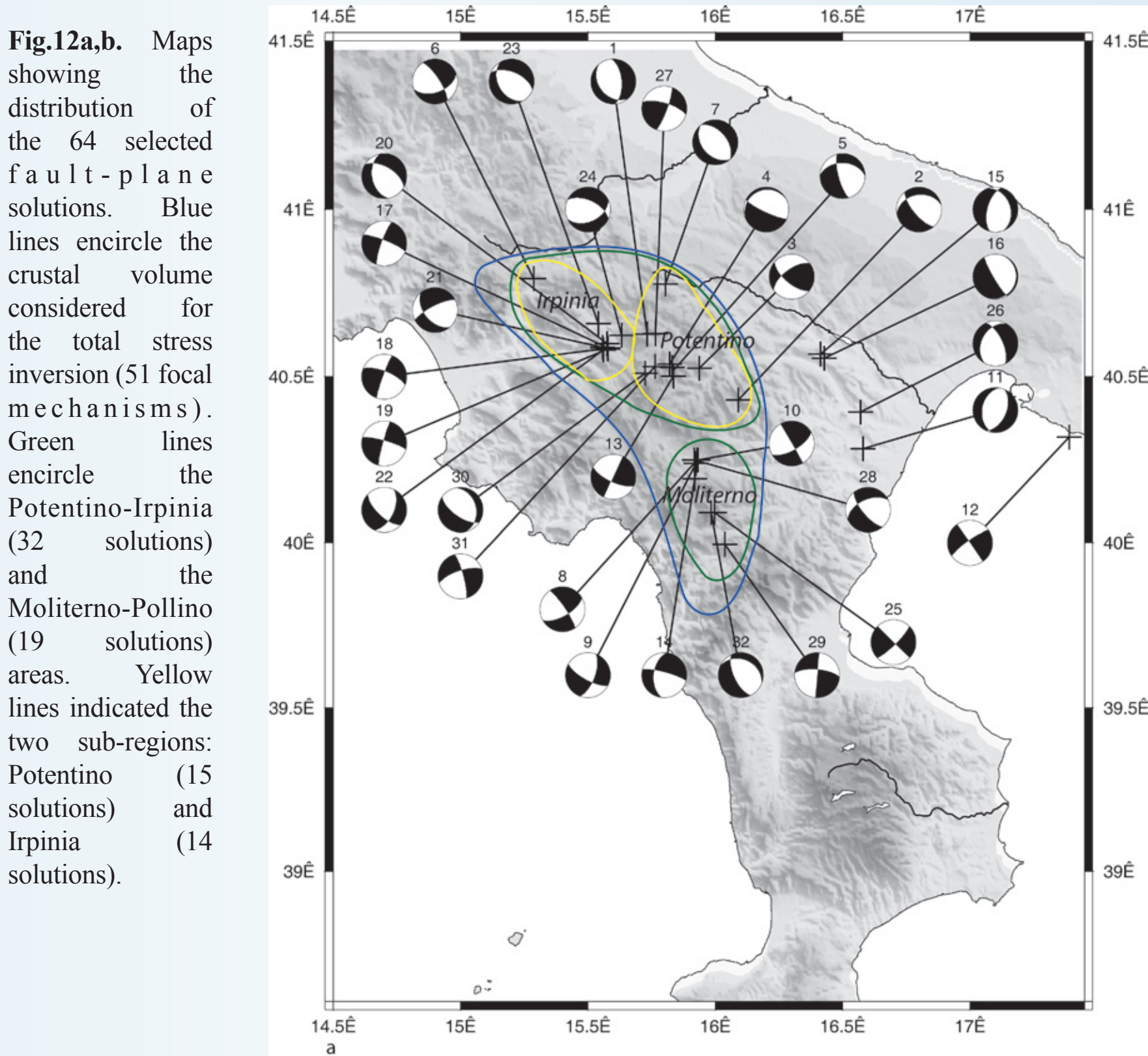
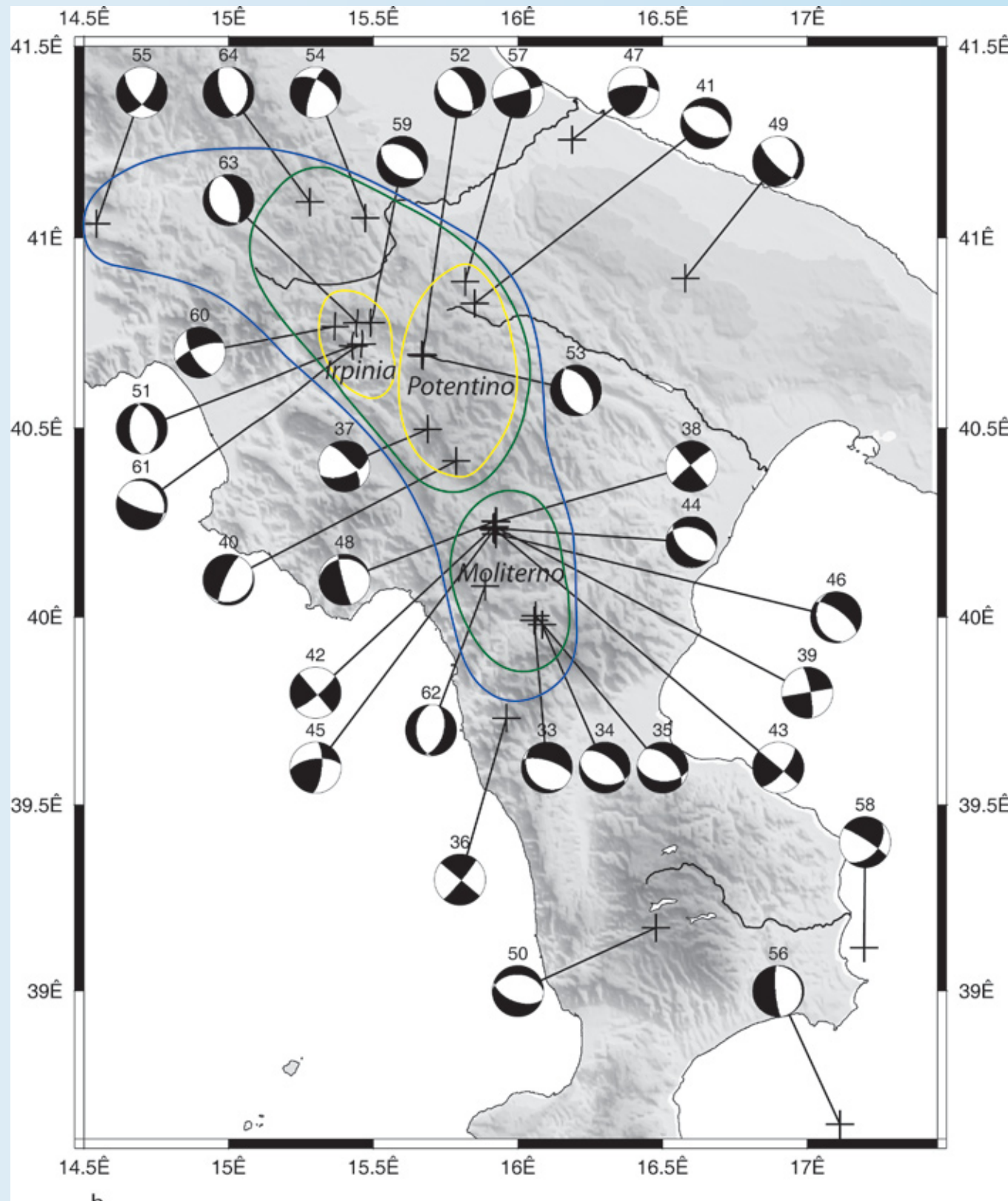


Fig.12a,b. Maps showing the distribution of the 64 selected fault-plane solutions. Blue lines encircle the crustal volume considered for the total stress inversion (51 focal mechanisms). Green lines encircle the Potentino-Irpinia (32 solutions) and the Moliterno-Pollino (19 solutions) areas. Yellow lines indicated the two sub-regions: Potentino (15 solutions) and Irpinia (14 solutions).



## Focal mechanism and stress field

Finally we computed 166 fault plane solutions of earthquakes localized in the study area. From this data set we selected 64 fault plane solutions following the two output quality factors Qf and Qp of the FPFIT code (Reasenberg and Oppenheimer, 1985). The average number of polarities for event used in this study is 12 (Fig.12a, Fig.12b). Focal mechanisms calculated in this work are in large part normal and strike-slip solutions and their tensional axes (T-axes) have a generalized NE-SW orientation. We used the FMSI code (Gephart,1990) to investigate the stress field in the study region. We rejected the fault-plane solutions of events with hypocentral depth  $\geq 30$  km and those isolated, outside to the Apenninic chain area. In the first step we apply the inversion technique to a 51 fault-plane solution dataset. Average misfit is quite large (7.9) indicating an inhomogeneous stress field distribution within the considered crustal volume. Notwithstanding this the minimum compressive stress axis ( $\sigma_3$ ) is sub-horizontal with trend of 231° (Fig.13a). We performed two new inversions dividing the 51 events dataset into two sub-volumes (see green lines in fig. 12a, b): one including the Potentino and Irpinia areas (32 focal mechanisms), and the other including the Moliterno area and the north-western Pollino range (19 fault-plane solutions). The inversion of the first dataset (Fig. 13b) shows a relatively high average misfit (7.4) and approximately the same stress field orientation as in the 51 events dataset inversion, while the inversion for the Moliterno-Pollino area (Fig. 13c) shows an 5.1 average misfit. We subdivided this new dataset into two sub-regions (see yellow lines in fig. 12a, b). The first with 15 fault-plane solutions belonging to the Potentino area, and the second with 14 focal mechanisms within the Irpinia area. Only the Irpinia dataset inversion (Fig. 13d) shows an average misfit smaller than 6.0, while the inversion for the Potentino area (Fig.13e) shows a value of 6.3 indicating a small heterogeneity inside the investigated crustal volume.

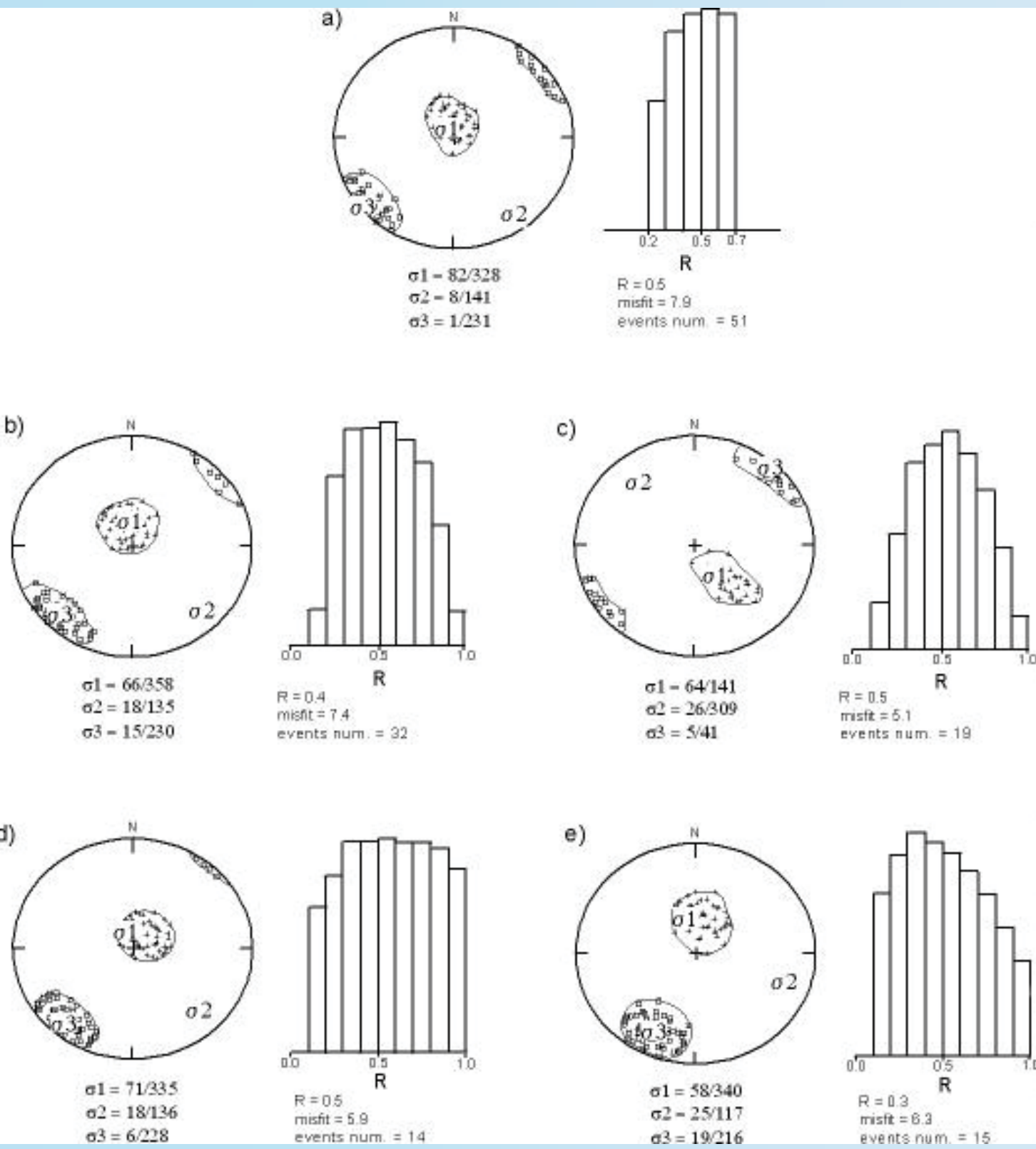


Fig. 13. Stress inversion results using: a) 51 solutions (Apenninic chain); b) 32 solutions (Irpinia-Potentino); c) 19 solutions (Moliterno-Pollino); d) 14 solutions (Irpinia); e) 15 solutions (Potentino). For each inversion is shown the stereonet plot with the 95% confidence limits for  $\sigma_1$  (small crosses) and  $\sigma_3$  (small squares) and the histogram illustrating the uncertainty in the R parameter. Plunge and trend for the three principal stress axes are shown below the histograms.

## Conclusions

- The Southern Italy seismicity in the area including the Lucanian Apennines and surrounding regions is carefully analyzed using a high-quality dataset of waveforms collected from a dense monitoring of the region in the last six years.
- We computed the Vp/Vs ratio using a modified Wadati method, obtaining a value of 1.83.
- An analysis for the one-dimensional (1D) velocity model that approximates the seismic structure of the study area is carried out obtaining the regional model called *Test8*. The Moho is put at 35 km depth consistently with others studies.
- We relocated 359 earthquakes with magnitude greater than 2.0. Relocations are well constrained and significantly improved with respect to those obtained by RSNC data only and by other previous studies concerning the period 2001-2002.
- Seismicity is concentrated beneath the Apenninic chain with an evident gap in the area between Pollino and Sila range (Fig.9, section MN). Conversely, at the eastern margin of the chain, beneath the Bradano foredeep and the Apulian foreland, seismicity is deeper and sparse (Fig 9, sections AB, CD, EF, GH, IL).
- The 64 selected focal mechanisms show mostly normal and strike-slip solutions. The tensional axes (T-axes) display a generalized NE-SW orientation.
- We calculate the stress field inversion for three different regions.
- The Irpinia area shows an average misfit smaller than 6.0 and a  $\sigma_3$  axes NE-SW oriented with 6° of plunge (Fig.13d).
- The Potentino area characterized by a stress field heterogeneous and the minimum compressive stress axis  $\sigma_3$  oriented NNE-SSW with 19° of plunge (Fig.13e).
- The area between Moliterno and northwestern Pollino range shows a stress inversion with a small value of misfit (5.1) suggesting a stress field homogeneity. In this region  $\sigma_3$  is NE-SW oriented with sub-horizontal plunge (Fig.13c).

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